

## ERASING METHOD IN NON-VOLATILE MEMORY DEVICE

### CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to Korean Patent Application No. 2001-35424, filed on June 21, 2001, which is commonly owned and incorporated by reference herein.

### BACKGROUND

#### 1. Technical Field:

The present invention relates to a semiconductor memory device and, more particularly, to a method for an erase operation in a non-volatile semiconductor memory device.

#### 2. Description of Related Art:

Generally, non-volatile electrically erasable and programmable read only memories (EEPROMs) are classified into floating gate EEPROMs and polysilicon-blocking oxide-silicon nitride-tunnel oxide-semiconductor (SONOS) EEPROMs.

EEPROMs store data in a floating gate of polysilicon or entrap data in a nitride layer while increasing or decreasing a threshold voltage to perform a program (or write) operation. When reading the stored data, EEPROMs use a sensing circuit to apply a read voltage ( $V_r$ ) and sense a current flowing to a channel. Also, to perform an erase operation, EEPROMs remove the stored data in the polysilicon or the nitride layer.

In SONOS EEPROMs, a read operation is performed when stored data is varied. Accordingly, the stored data must be completely removed throughout a channel to secure reliability of the device. Otherwise, the read and erase operations are repeatedly performed to accumulate data continuously, and the read operation can be erred by the varying of a threshold voltage.

Fig. 1 is a cross-sectional view showing a memory cell according to a conventional program method in a SONOS EEPROM device. Fig. 2 shows a memory cell according to a conventional erase method in a SONOS EEPROM device. Fig. 3A shows a memory cell according to another conventional erase method in a SONOS EEPROM, and Fig. 3B illustrates a waveform of the voltages applied to the memory cell of Fig. 3A. In Fig. 3B, a traverse axis represents time (t), and a longitudinal axis represents applied voltages.

Referring to Fig. 1, a memory cell 50 comprises a P-type bulk region 10, spaced drain and source regions 12, 14 formed in the P-bulk region 10, a channel region 13 formed between the drain and source regions 12, 14, an ONO layer 22 (comprising a tunnel oxide 16, a nitride 18, and a blocking oxide 20 layer) formed on the channel region 13, and a polysilicon gate electrode 24 formed on the ONO layer 22. To program the memory cell, the drain and source regions 12, 14 and the P-bulk region 10 are grounded through a metal contact and a program voltage  $V_{pp}$  is applied to the gate electrode 24. And, electrons are entrapped in the nitride layer 18 through a thin tunnel oxide layer 16 by F-N tunneling (Fowler-Nordheim tunneling).

In a conventional erase method shown in Fig. 2, a negative program voltage  $-V_{pp}$  is applied to a gate electrode 24 with the drain and source regions 12, 14 and a P-

bulk region 10 being grounded. Holes are then injected from the P-bulk region 10 to a tunnel oxide layer 16 and a nitride layer 18, compensating the entrapped electrons in the program operation to perform the erase operation. Unfortunately, it is difficult to form and apply the negative voltage  $-V_{pp}$  to the gate electrode 24.

5 A memory cell according to another conventional erase method, shown in Fig. 3A, further comprises a pocket P-well 11 formed in the N-bulk region 10. In an erase operation, the gate electrode 24 is grounded, and an erase voltage  $V_{pp}$  is applied to the drain and source regions 12,14, the pocket P-well 11, and the N-bulk region 10 through a metal contact. The applied voltages are schematically shown in Fig. 3B. One  
10 disadvantage associated with the memory device in Fig. 3A is that the pocket P-well 11 must separately be formed, thus increasing the complexity and processing costs.

Although not shown in Figs. 1-3, another conventional erase method can be performed by grounding a gate electrode and the bulk region, and equivalently applying an erase voltage to source and drain regions. In the erase method, a high-energy hole (so-  
15 called "hot hole"), formed at both sides (i.e., source and drain regions) of a channel, is vertically injected through a source region-to-gate electrode junction side and a drain region-to-gate electrode junction side. However, the erase method cannot fully perform the erase operation at the center of the channel. Therefore, the entrapped electrons are not removed and are continuously accumulated in a nitride layer over the channel center. As  
20 a result, a threshold voltage is heightened and a sensing margin is reduced.

Thus, a need exists for a circuit framework that generates a negative voltage without occupying additional area in a semiconductor device.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an efficient erase method in a non-volatile semiconductor memory device capable of achieving a reliable erase operation throughout a channel region, which does not require applying a negative voltage or performing a pocket well process.

According to one aspect of the present invention, a non-volatile memory device is provided which enables an effective erase operation according to the invention. The device comprises a bulk region of a first conductive type, spaced first and second impurity diffusion regions of a second conductive type formed in the bulk region, a charge storing layer formed between the first and the second impurity diffusion regions, and a conductive electrode formed on the charge storing layer. The method for performing an erase operation in the non-volatile memory device comprises the steps of: applying a bulk voltage to the bulk region for a predetermined erase time; applying a gate voltage to the conductive electrode for the predetermined erase time, the gate voltage being greater than or equal to the bulk voltage; applying a first electrical signal to the first impurity diffusion region for the predetermined erase time, the first electrical signal comprising a voltage that is greater than the gate voltage; and applying a second electrical signal to the second impurity diffusion region for the predetermined erase time, the second electrical signal comprising a voltage that is greater than the gate voltage, wherein the voltage of the first electrical signal is different from the voltage of the second electrical signal.

The voltage level of the first electrical signal is switched between a first voltage and a second voltage at least one time, during the predetermined erase time, wherein the

first and second voltages are greater than the gate voltage. The second electrical signal is substantially equal to the first and second voltages when the first electrical signal is substantially equal to the second and the first voltages, respectively for the predetermined erase time. For example, the first voltage ranges from about 2V to about 6V, and the  
5 second voltage is about 10V.

According to another aspect of the present invention, a method for performing an erase operation in a memory cell, comprising a bulk region of a first conductive type, spaced source and drain regions of a second conductive type formed in the bulk region, and a gate electrode formed between the source and drain regions is provided. The  
10 method comprises the steps of: applying a first voltage to the source region and a second voltage to the drain region for a portion of a predetermined erase time; and applying the second voltages to the source region and the first voltage to the drain region for a portion of the predetermined erase time.

According to further aspect of the present invention, a method for performing an  
15 erase operation in a non-volatile memory device, comprising a bulk region of a first conductive type, spaced source and drain regions of a second conductive type formed in the bulk region, and a gate electrode formed between the source and drain regions, is provided. The method comprises the steps of: applying a first voltage and a second voltage to the source and drain regions, respectively, for a predetermined erase time;  
20 applying a third voltage to the gate electrode, wherein the potential differences between the third voltage and the first and second voltages are sufficient to generate electric fields between the gate electrode and the source and drain regions to inject holes into the source and drain regions, respectively; and switching the first voltage to the drain region and the

second voltage to the source region at least one time during the predetermined erase time.

Advantageously, according to the present invention, by applying and switching different voltage levels to source and drain regions, respectively for predetermined erase time, hole is easily injected into the source and drain regions, and a channel lateral surface. Therefore, it is possible to achieve uniform and high-speed erase operation.

These and other objects, aspects, features, and advantages of the present invention will become apparent from the following detailed description of preferred embodiments, which is to be read in connection with the accompanying drawings.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a cross-sectional view of a memory cell for performing a conventional program method in an EEPROM;

Fig. 2 is a cross-sectional view of a memory cell for performing a conventional erase method in an EEPROM;

Fig. 3A is a cross-sectional view of a memory cell for performing another conventional erase method in an EEPROM;

Fig. 3B is a diagram showing voltage waveforms that are applied to the memory cell of Fig. 3A to perform a conventional erase operation;

Fig. 4A is a cross-sectional view showing a memory cell for performing an erase operation according to one aspect of the invention;

Fig. 4B is a diagram showing voltage waveforms that are applied to the memory cell of Fig. 4A for performing an erase operation according to one aspect of the invention; Fig. 4C is a diagram showing voltage waveforms that are applied to the

memory cell of Fig. 4A for performing an erase operation according to another aspect of the invention;

Fig. 4D is a graph showing hole injecting directions based on the applied voltages of Fig. 4B;

5 Fig. 5A is a diagram showing voltage waveforms that are applied to the memory cell of FIG. 4A for performing an erase operation according to another aspect of the invention;

Fig. 5B is a cross-sectional view of a memory cell showing hole injection directions based on the applied voltages of Fig. 5A;

10 Fig. 5C is a graph showing an amount of injected holes of Fig. 5B as a function of source and drain voltages and channel length;

Fig. 5D is a diagram showing voltage waveforms that are applied to the memory cell of Fig. 4A for performing an erase operation according to another aspect of the invention;

15 Figs. 6A and 6B are diagrams showing voltage waveforms that are applied to the memory cell of Fig. 4A for performing erase operations according to further aspects of the invention;

Fig. 7 is a graph comparing the relationship between a threshold voltage shift and erase time between a conventional erase method and an erase method of the invention; and

20 Figs. 8A through 8C are graphs comparing the relationship between an endurance characteristic and the number of write/erase cycle between a conventional erase method and an erase method of the invention, respectively.

## DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention relates to methods for erasing data in a non-volatile memory device. Although preferred embodiments of the present invention are described using a SONOS EEPROM device, it is understood that the present invention can be applied to a floating gate EEPROM device. Also, notwithstanding that an N-channel of the SONOS EEPROM device is described, the present invention is equally applicable to P-channel structures without departing from the spirit of the present invention.

Referring to Fig. 4A, an erase voltage is applied to a programmed memory cell transistor 500 of a SONOS EEPROM device. The memory cell transistor 500 comprises a P-type bulk region 100, spaced first and second impurity diffusion regions 120 and 140 formed in the P-type bulk region 100, an N-type channel region 130 formed between the impurity diffusion regions 120 and 140, a charge storing layer 220 (which comprises a tunnel oxide layer 160, a storage storing nitride layer 180, and a blocking oxide layer 200) formed on the N-type channel region 130, and a conductive electrode 240 formed on the charge storing layer 220. The first and second impurity diffusion regions 120 and 140 comprise drain and source regions, respectively, and are formed by implanting N-type impurities into the P-type bulk region 100. The conductive electrode 240 comprises a polycide gate electrode. A metal contact is formed in the P-type bulk region 100, so that the memory cell transistor 500 in a SONOS EEPROM device has four terminals.

In a program operation, the bulk region 100, the drain region 120, and the source region 140 are grounded and a program voltage  $V_{pp}$  is applied to the gate electrode 240. Then, electrons are entrapped in the charge storing nitride layer 180 through the tunnel oxide layer 160 by F-N tunneling, increasing a threshold voltage of the cell transistor.



On the other hand, in a floating gate EEPROM device, the charge storing layer 220 comprises a tunnel oxide layer, a floating gate layer, and a dielectric layer, and charges are stored in the floating gate layer.

5 An erase method according to one embodiment of the invention will now be described in further detail. Unlike a conventional method, the present invention does not require a separate pocket well process and a negative voltage applied to a gate. Instead, a bulk voltage  $V_b$  of about 0V is applied to the bulk region 100 (i.e., the bulk region 100 is grounded), and a gate voltage  $V_g$  of about 0V or higher voltage is applied to a gate electrode 240. Drain and source voltages  $V_d$  and  $V_s$  (which are higher than the gate voltage  $V_g$ ) are applied to the drain and source regions 120 and 140, respectively. 10 Preferably, the drain and source voltages  $V_d$  and  $V_s$  are different from each other in magnitude.

It is preferable that the gate voltage  $V_g$  is grounded for easy injection of a hot hole. This is because a hot hole is easily injected when the potential differences between the gate voltage  $V_g$  and the source voltage  $V_s$ , and between the gate voltage  $V_g$  and the drain voltage  $V_d$  are, high. For instance, a negative voltage may be applied to a gate electrode for higher potential difference. 15

In an embodiment of the present invention, with an N-type channel, relative voltage levels are as follows: drain voltage  $V_d >$  source voltage  $V_s >$  gate voltage  $V_g \geq$  bulk voltage  $V_b$ , or source voltage  $V_s >$  drain voltage  $V_d >$  gate voltage  $V_g \geq$  bulk voltage  $V_b$ . Further, and more preferably, the drain voltage  $V_d$  and the source voltage  $V_s$  may be switched with each other. The drain voltage  $V_d$  and the source voltage  $V_s$  are varied with a resisting pressure characteristic of a P-N junction (which is formed between 20

an N-type source region and a drain region on a P-type bulk region). For example, if the P-N junction has a resisting characteristic of about 12V, a drain voltage is about 10V, a source voltage is about 2V-6V, and a gate voltage is grounded. Therefore, intensities of applied voltages can be controlled by a resisting pressure characteristic of a P-N junction.

5 In Fig. 4B, a traverse axis (or X-axis) represents an erase time ( $T_e$ ) of voltages applied to each terminal, and a longitudinal axis (Y-axis) represents intensities of the applied voltages. As shown in Fig. 4B, a gate voltage  $V_g$  and a bulk voltage  $V_b$  are maintained at about 0V (grounded). For predetermined erase time ( $T_e$ ), a source voltage  $V_s$  is about 4V (which is higher than the gate voltage  $V_g$ ), and a drain voltage  $V_d$  is about 10V (which is higher than the gate voltage  $V_g$ ). In another embodiment of the present invention, a drain voltage  $V_d$  may be switched with a source voltage  $V_s$ . For example, as shown in Fig. 4C, a source voltage  $V_s$  is about 10V and a drain voltage  $V_d$  is about 4V for the erase time  $T_e$ .

15 In this embodiment, the source voltage and the drain voltage are different from each other. When the drain voltage  $V_d$  is higher than the source voltage  $V_s$ , as shown in Fig. 4B, electric fields ( $\overrightarrow{E_v}$ ) are generated between a gate electrode 240 and a drain region 120 and electric fields ( $\overrightarrow{E_l}$ ) are generated between the drain region 120 and a source region 140, as shown in Fig. 4D. The  $\overrightarrow{E_v}$  and the  $\overrightarrow{E_l}$  are followings:  $\overrightarrow{E_v} = (V_d - V_g)/d_1$  (wherein,  $d_1$  is a distance between a gate electrode and a drain region); and  $\overrightarrow{E_l} = (V_d - V_s)/d_2$  (wherein,  $d_2$  is a distance between a source region and a drain region). Because of these electric fields, a hot hole (which is created at a drain region) has not only a vertical element between a drain region and a gate electrode, but also a horizontal

element between the drain region and a source region (i.e., a horizontal direction along a channel). Thus, a hole is injected according to a direction based on a vector sum of the two elements ( $\vec{E}_{\text{hole}} = \vec{E}_V + \vec{E}_I$ ). Accordingly, an erase operation is effectively performed throughout the channel region.

5           More preferably, a drain voltage  $V_d$  and a source voltage  $V_s$  are switched at least one or more times during an erase time ( $T_e$ ). For example, as shown in Fig. 5A, a drain voltage  $V_d$  is about 10V and a source voltage  $V_s$  is about 4V for a predetermined time (e.g.,  $T_e/2$ ), and the voltages  $V_d$  and  $V_s$  are switched with each other for the remaining time ( $T_e/2$ ), wherein the drain voltage  $V_d$  is about 4V and the source voltage  
10    $V_s$  is about 10V. Furthermore, as shown in Fig. 5D, a higher voltage ( $> 10V$ ) may be applied to the source voltage  $V_s$  and a lower voltage ( $< 4V$ ) may be applied to the drain voltage  $V_d$  for a predetermined time ( $T_e/2$ ), and vice versa for the remaining time ( $T_e/2$ ). It is to be understood that these voltage levels and switching times are for purposes of illustration and that persons skilled in the art can modify the switching time of a source  
15   voltage and a drain voltage and the magnitude of the voltages. For example, the first switching time and the second switching time may be different from each other. Furthermore, the total switching time may be longer than the erase time ( $T_e$ ).

Fig. 5B shows hole-injecting directions in source and drain regions when applied voltages are switched between the source region and the drain region. An arrow ①  
20   illustrates a hole injecting direction when a higher voltage is applied to a drain region, and an arrow ② illustrates a hole injecting direction when a higher voltage is applied to a source region. As a result, a uniform erase operation can be performed throughout a channel by switching the voltages applied to source and drain regions. This is because

holes are injected to a channel side direction by an electric field formed between the source and drain regions.

Fig. 5C illustrates a relationship between an amount of injected holes and a channel length, wherein a traverse axis represents a channel length, and a longitudinal axis represents an amount of injected holes. If a higher voltage is applied to a drain region, relatively more amount of holes is injected into the drain region (as shown by line ①). If a higher voltage is applied to a source region, relative more amount of holes is injected into the source region (as shown by line ②). Thus, if applied voltages are switched between the source region and the drain region, the total of amounts of holes in the source and drain regions leads to uniform hole injection throughout the entire channel region (as shown by line ③).

Figs. 6A and 6B are diagrams showing voltage waveforms that are applied to the device in Fig. 4A to perform erase operations according to other embodiments of the present invention. For example, in Fig. 6A, voltages of source and drain regions are switched twice (e.g., the voltages are switched every  $T_e/3$ ). Although, a higher voltage is initially applied to the source region, the higher voltage may initially be applied to the drain region. Further, in Fig. 6B, voltages of source and drain regions are switched four times (e.g., the voltages are switched every  $T_e/4$ ). As mentioned above, in other embodiments, switching times may be different from each other, and the total switching time may be longer than an erase time  $T_e$ .

Fig. 7 is a graph showing the relationship between erase time and a threshold voltage shift according to a conventional erase method and an erase method of the present invention. The threshold voltage shift is a threshold voltage change between a program

operation and an erase operation. In general, a program operation is performed by applying 11V to a gate electrode, applying 6V to a drain region, and grounding a source region and a bulk region. The gate electrode is preferably made of polycide having a thickness of about 2000Å. An ONO layer comprises an oxide-nitride-oxide stacking layer each having a thickness of 80Å. Arsenic (As) is implanted into the source and drain regions by 60keV with a dose of  $5 \times 10^{15}$  atoms/cm<sup>2</sup>, and into a channel region by 60keV with a dose of  $1.0 \times 10^{12}$  atoms/cm<sup>2</sup>. In Fig. 7, a traverse axis (or X-axis) represents an erase time (second), and a longitudinal axis (or Y-axis) represents a variation of a threshold voltage (volt).

Reference symbol "I" represents a conventional erase method, wherein a bulk region and a gate electrode are grounded, and 10V is applied to source and drain regions for a predetermined time ("case 1"). Reference symbols "II" and "III" represent erase methods according to the present invention. With symbol "II", as shown in Fig. 4B, a bulk region and a gate electrode are grounded, 4V is applied to a source region, and 10V is applied to a drain region for the identical erase time ("case 2"). With symbol "III", 10V/4V and 4V/10V are applied to source and drain regions under the same condition as case 2, for half of an erase time ( $T_e/2$ ), respectively ("case 3"). As shown in Fig. 7, a threshold voltage shift of the present invention ("case 2" or "case 3") is greater than that of the conventional method (case 1). That is, a threshold voltage shift in applying different voltages to source and drain regions is greater than that in applying the same voltage to the source and drain regions. Advantageously, when voltages of the source and drain regions is switched with each other, a better result can be obtained.

Figs. 8A through Fig. 8C are graphs illustrating the relationship between an endurance characteristic of a memory cell and the number of write/erase cycles according to a conventional erase method and an erase method of the present invention, respectively. Fig. 8A shows an endurance characteristic of a memory cell according to a conventional erase method (i.e., "case 1"), Fig. 8B and 8B show endurance characteristics of memory cell according to an erase method of the present invention ("case 2" and "case 3"), respectively. In each drawing, a traverse axis (X-axis) represents the number of write/erase cycles, and a longitudinal axis (Y-axis) represents a cell threshold voltage (volt). The threshold of the memory cell is a gate voltage when a 1.5V is applied to a drain region and a drain current is 1 $\mu$ A.

Figs. 8A-8C show that an endurance characteristic of a memory cell is improved from "case 1" through "case 2" to "case 3". That is, an endurance characteristic of a memory cell according to the present invention is better than that of the conventional erase method. This is because, in the present invention, electric fields, which are formed by a voltage difference between source and drain regions, generate implanting elements that are added toward a channel lateral surface, and a uniform erase is performed throughout the channel.

According to the present invention, SONOS EEPROM devices may be applied to N-channel devices, P-channel devices, and floating gate EEPROM devices. And, SONOS EEPROM devices do not need a separate pocket well for applying a voltage to a bulk region. Furthermore, in an N-channel EEPROM, a uniform hole injection is achieved throughout a channel to enhance a reliability of erase operation.

Thus, it is understood that while the various particular embodiments set forth

herein have been described in detail, the present invention could be subject to various changes, substitutions, and alterations without departing from the spirit and scope of the invention. Accordingly, the present invention is intended to be limited only as defined by the appended claims.